Effects of the interaction of sex and food intake on the relation between energy expenditure and body composition[1–3]

David R Paul, Janet A Novotny, and William V Rumpler

ABSTRACT

Background: The relation between physical activity energy expenditure (PAEE) and percentage body fat (%BF) is not very strong in the general population. It is possible that variables such as sex, food intake, or both may in part explain this poor coupling.

Objective: This study was designed to show the relation between PAEE and %BF and to determine whether sex, food intake, or both influence the strength of the relation.

Design: We used doubly labeled water or energy intake balance, indirect calorimetry, dietary interview, and dual-energy X-ray absorptiometry to measure total energy expenditure (TEE), resting energy expenditure (REE), food intake, and %BF, respectively, in 91 healthy persons (women: aged 48 y, 38.6%BF, $n = 47$; men: aged 47 y, 24.1%BF, $n = 44$).

Results: TEE, PAEE, and REE were significantly lower in women than in men. TEE was related to %BF in women ($r = 0.53$, $P < 0.0001$) but not in men ($r = -0.22$, $P > 0.05$). The relation between PAEE and %BF was significant in men ($r = -0.34$, $P < 0.03$) but not in women. PAL was also significantly related to %BF in men ($r = -0.36$, $P < 0.02$) but not in women. Macronutrient intake (% of total energy) did not differ significantly between the sexes, but carbohydrate ($r = -0.44$, $P < 0.003$) and fat ($r = 0.31$, $P < 0.04$) intakes were significantly related to %BF in women.

Conclusions: These results suggest that the relation between PAEE and %BF is stronger in men than in women. Macronutrient composition seems have a stronger influence on %BF in women than in men. *Am J Clin Nutr* 2004;79:385–9.

KEY WORDS Doubly labeled water, physical activity, energy expenditure, body fat, body composition, food intake

INTRODUCTION

Despite the widely held notion that maintaining or reducing body weight or fat is facilitated by an increase in physical activity, the relation between physical activity energy expenditure (PAEE) and body composition [percentage body fat (%BF), body mass index (in kg/m^2), or both] is not very strong (1–6). These results suggest that maintenance of a healthy body weight or body composition, or both, may not be related to PAEE alone and that other variables related to energy balance (such as the regulation of food intake) may be equally important.

An additional variable that may alter the strength of this relation is sex. Two studies have indicated that the %BF of active men is likely to be lower than that of less active men (2, 7), but the same relation was not observed in women (2). Westerterp and Goran (2) hypothesized that the difference in the relation of PAEE and %BF between the sexes may be due to an increase in energy intake (EI) on the part of active women to compensate for their high degree of physical activity. Unfortunately, Westerterp and Goran did not report EI data. The lack of food intake data is significant because changes in energy balance, body weight, and fat are smaller in women than in men undergoing a similar exercise challenge (8, 9).

Overall, few studies show the apparent sex difference in the relation between energy expenditure (EE) and body composition, and none report food intake data. Therefore, the purposes of the present study were to investigate the relation between EE and body composition in women and in men and to examine the importance of food intake to this relation.

SUBJECTS AND METHODS

Subjects

Ninety-one healthy adult volunteers (47 women and 44 men; **Table 1**) participated in this study after completing a brief questionnaire on health status, weight-reduction attempts, body weight history, smoking status and history, physical injuries, and time spent in exercise (10). Subjects reporting changes in physical activity, smoking status, body weight, or EI during the previous 6 mo were excluded from the study. Women who were currently pregnant or had been pregnant during the past 12 mo were also excluded from the study. The study protocol was approved by the Johns Hopkins University Bloomberg School of Public Health Committee on Human Research, and written informed consent was obtained from each subject before participation.

Energy expenditure

Resting EE (REE) was measured with the use of respiratory gas analysis using a ventilated hood for 40 min in the early morning after a 12-h overnight fast, as described previously (11). REE was calculated from the central 20 min of respiratory gas

[1] From the Diet and Human Performance Laboratory, Beltsville Human Nutrition Research Center, Agricultural Research Service, US Department of Agriculture, Beltsville, MD.

[2] Supported by the US Department of Agriculture.

[3] Address reprint requests to JA Novotny, USDA, DHPL, 308 Center Drive, Beltsville, MD 20705. E-mail: novotny@bhnrc.arsusda.gov.

Received December 23, 2002.
Accepted for publication August 29, 2003.

TABLE 1
Characteristics of the subjects[1]

Characteristic	Women ($n = 47$)	Men ($n = 44$)
Age (y)	48 ± 10	47 ± 11
Body weight (kg)	74.2 ± 18.0	83.2 ± 12.8[2]
Height (cm)	164.2 ± 5.6	177.4 ± 6.9[2]
Body fat (%)	38.6 ± 8.9	24.1 ± 6.5[2]
BMI (kg/m^2)	27.4 ± 6.3	26.4 ± 3.8

[1] $\bar{x}$ ± SD.
[2] Significantly different from women, $P < 0.05$ (ANOVA).

TABLE 2
Energy expenditure–related variables in 47 women and 44 men[1]

	Women	Men
TEE (MJ/d)	10.3 ± 1.9	12.7 ± 1.4[2]
REE (MJ/d)	6.3 ± 0.9	7.8 ± 0.9[2]
PAL	1.69 ± 0.19	1.64 ± 0.19
PAEE (MJ/d)	4.1 ± 1.4	4.9 ± 1.3[2]

[1] $\bar{x}$ ± SD. TEE, total energy expenditure; REE, resting energy expenditure; PAL, physical activity level (TEE/REE); PAEE, physical activity energy expenditure (TEE − REE).
[2] Significantly different from women, $P < 0.05$ (ANOVA).

data by using the Weir equation (12). The %BF was measured by using dual-energy X-ray absorptiometry (Lunar DPX; Lunar Radiation Corporation, Madison, WI).

TEE was measured by using the doubly labeled water method (27 women and 12 men) or the EI balance method (20 women and 32 men). These 2 methods have been shown in our laboratory to result in TEE values that agree within 0.3% (13). TEE via EI balance was measured during a controlled feeding study that included a weight-maintenance diet ≥12 wk in length. During the controlled feeding period, subjects ate only foods prepared by the Beltsville Human Nutrition Research Center (BHNRC). Each week, the subjects' daily weights were reviewed, and EIs were altered in increments of 0.84 MJ/d to achieve weight maintenance. The first 4 wk of the controlled feeding period were not included in the calculation of weight-maintenance EI so that the initial adjustment period would not adversely affect the results. TEE was considered the average daily EI value during the 8-wk weight-maintenance period that followed the first 4 wk of controlled feeding. Diet compositions and EIs were calculated by a registered dietitian using NUTRITIONIST 4 software (First DataBank, San Bruno, CA).

TEE in the remaining subjects was measured by using the doubly labeled water method. Subjects reported to the BHNRC between 0630 and 0900, at which time they received an oral dose of $H_2{}^{18}O$ (0.12 g/kg body wt) and ^2H_2O (0.55 g/kg body wt). Urine samples were collected immediately before the dose and on days 1, 2, 3, 12, 13, and 14 after the dose. The first sample was collected ≈24 h after the dose. Subjects recorded the specific time of sample collection on each of the collection days. Enrichment of deuterium and ^{18}O in urine samples was measured by infrared spectroscopy and isotope ratio mass spectrometry, respectively. TEE was calculated from the ^2H and ^{18}O decay kinetics as described by Schoeller (14). PAEE was calculated as the difference between TEE and REE. Physical activity level (PAL) was defined as the ratio of TEE to REE (15).

Energy intake

EI and macronutrient composition were determined by 24-h recall with the use of the dietary data collection system (16) used in the third National Health and Nutrition Examination Survey (10). The dietary interviews (2 per subject) were conducted at the BHNRC by a registered dietitian trained at the University of Minnesota Nutrition Coordinating Center. The recall, which is a triple-pass method, begins with the subjects' quick compilation of a list of food items consumed, which is followed first by an in-depth description of each food listed and then by a final review of foods and descriptions. The interviews were conducted 3–10 d apart and completed ≤2 wk before measurement of TEE. The nutrient composition data for the foods reported during the interviews were generated by using the University of Minnesota 1996 NUTRIENT DATABASE (versions 15–25; University of Minnesota Nutrition Coordinating Center, Minneapolis; 17). The EIs (% of total EI) of carbohydrate, protein, and fat were calculated without including the contribution of alcohol. Approximately 45% of the subjects abstained from alcohol consumption, and the overall alcohol intake was only ≈2% of total intake.

Statistical analysis

Pearson's product-moment correlations were used to determine the relation between variables. The significance of differences between the sexes was determined by using ANOVA software (version 8.02; SAS Institute, Cary, NC). Results are presented as mean ± SD.

RESULTS

Energy expenditure

TEE, REE, and PAEE were significantly greater for men than for women, but PAL did not differ significantly between the sexes (**Table 2**). Reported exercise was 1354.3 ± 1284.0 min/wk for women and 1585.8 ± 2586.2 min/wk for men. These differences were not significant.

TEE was significantly related to %BF in all subjects ($r = -0.26$, $P < 0.03$), but PAEE ($r = 0.27$, $P > 0.05$) and PAL ($r = -0.11$, $P > 0.05$) were not. When the men and the women were analyzed separately, the relation of TEE to %BF was significant in the women, and the relation of PAEE and PAL to %BF was significant in the men (**Figure 1**).

Food intake

Dietary recalls indicated that energy and macronutrient intakes were greater in men than in women (**Table 3**). These differences were no longer significant when macronutrient intake was expressed as a percentage of total daily EI (**Table 4**). There was no significant relation between %BF and macronutrient intake (% of total EI) in men (**Table 5**). However, there was a significant relation between %BF and macronutrient intake (% carbohydrate and fat intake) in women.

DISCUSSION

The results of the present investigation confirm those of previous studies indicating that the relation between PAEE and %BF is not very strong (1, 2, 5, 6) and is significant in men but not in women (2). According to the results of the dietary

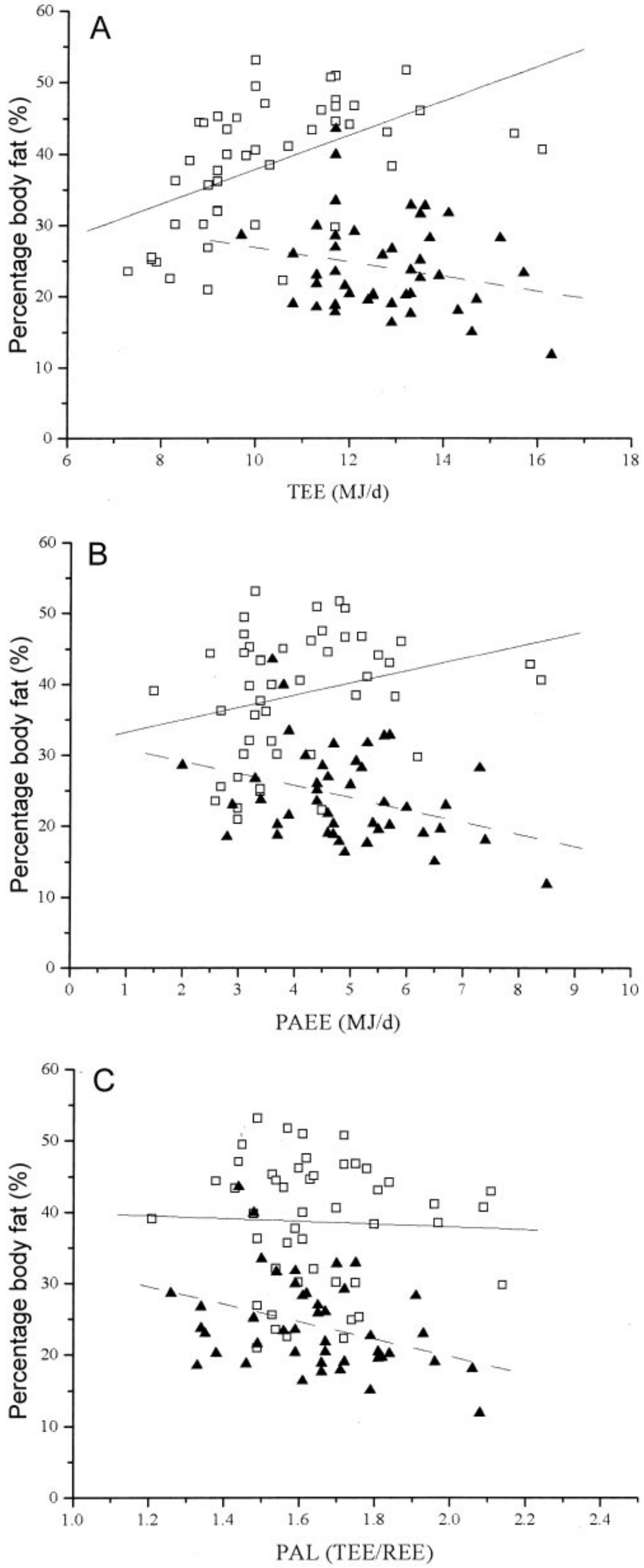

FIGURE 1. Relation between percentage body fat and energy expenditure [total energy expenditure (TEE), physical activity energy expenditure (PAEE), and physical activity level (PAL)] in 47 women (□) and 44 men (▲). TEE in women: $r = 0.53$, $P < 0.0001$; PAEE in women: $r = 0.27$, $P > 0.05$; PAEE in men: $r = -0.34$, $P < 0.03$; PAL in women: $r = -0.04$, $P > 0.05$; PAL in men: $r = -0.36$, $P < 0.02$ (Pearson's product-moment correlation).

TABLE 3
Macronutrient and total energy intake from dietary recall in 47 women and 44 men[1]

	Women	Men
Carbohydrate (g)	280.2 ± 87.0	381.7 ± 121.1[2]
Fat (g)	69.7 ± 29.3	105.6 ± 33.9[2]
Protein (g)	74.5 ± 22.6	105.7 ± 33.7[2]
Energy (MJ)	8.5 ± 2.4	12.1 ± 3.4[2]

[1] $\bar{x} \pm$ SD.
[2] Significantly different from women, $P < 0.05$ (ANOVA).

recalls, fat and carbohydrate intakes may explain part of this sex difference.

The relation between PAEE (and PAL) and %BF indicates that active subjects were not more likely to have a lower %BF than were sedentary subjects. It is difficult to explain the lack of strength in this relation. One possibility may be the confounding effects of body weight, fat-free mass, age, and height on measures of EE (16, 18, 19). For example, persons with a greater body weight may expend more energy in daily activities than may persons with a lower body weight, regardless of fitness status, activity level, or %BF. Another possibility could be that the relations between EE and %BF in this study (and others) are not very strong because weight gain is generally a long-term process and may not be representative of the EI and EE patterns sampled. Men and women generally gain 4.5 and 7.3 kg, respectively, over the course of 30 y (20). Thus, the physical activity, body-weight and -composition, and EI patterns sampled may not reflect the status of energy balance that existed over several years. Future studies should follow subjects for a longer period.

It is readily apparent that another reason for the overall poor relation between EE (TEE, PAEE, and PAL) and %BF derives from sex differences in the relation of EE and %BF. The results of the present study indicate that more active men tend to have a lower %BF than do less active men, but the same is not true in women. Similarly, a 16-mo exercise intervention study found a statistically significant fat loss (−4.9 kg) in men but essentially no change (−0.2 kg) in women (9). An alternative explanation for the sex-specific changes in body fat in response to EI could be the difference between the sexes in body weight, and thus EE should be expressed as a function of body weight (21). However, Carpenter et al (18) indicated that it is not appropriate to express TEE as a function of body weight, because the relation between those factors does not have a zero intercept. The relation between PAEE and %BF also does not have a zero intercept (22). Therefore, correcting EE for body weight is not appropriate because it introduces significant bias into the results (23). Another means of comparing the sexes is the use of PAL, because the effect of body

TABLE 4
Macronutrient intake (% of total energy intake) from dietary recalls in 47 women and 44 men[1]

Macronutrient	Women	Men
	%	
Carbohydrate	55.2 ± 10.6	52.3 ± 7.2
Fat	30.6 ± 9.2	32.6 ± 5.7
Protein	14.7 ± 2.8	14.6 ± 2.8

[1] $\bar{x} \pm$ SD. There were no significant differences between the sexes (ANOVA).

TABLE 5
Relation between macronutrient intake (% of total energy intake) by dietary recall and percentage body fat in 47 women and 44 men[1]

Macronutrient	Women	Men
	%	
Carbohydrate	−0.44[2]	0.03
Fat	0.31[2]	0.06
Protein	0.26	−0.11

[1] $\bar{x} \pm$ SD.
[2] Significant correlation with percentage body fat, $P < 0.05$ (Pearson's product-moment correlation).

weight is negated when EE is expressed as PAL (15). When EE was expressed as PAL, %BF was still more likely to be lower in more active men than in less active men, whereas the same was not true in women.

The results of dietary recalls indicate that women with higher fat and lower carbohydrate intakes have a concomitantly higher %BF. There are many possible explanations for the relation between food intake and body fat observed in this study. One of these explanations may be the tendency for foods high in fat also to be energy dense (24). Foods that have a high energy density are associated with higher overall EI (25, 26), which increases the likelihood of a positive energy balance and the accumulation of body fat. Women with higher %BF may tend to select foods that are high in fat and low in carbohydrate (or energy dense), without compensating for the higher EI by increasing their EE.

There is another possible role for food intake in explaining the poor relation between PAEE and %BF in women. A number of investigations indicated that women may compensate for EE by increasing EI to a greater extent than do men (2, 27, 28). Therefore, the sex differences observed in this investigation may be related to the notion that women with more active lifestyles tend to compensate with an increase in food intake to a greater extent than do men. Stubbs et al (27, 28) performed 2 separate experiments in which sedentary men and women increased TEE over 7 d by implementing 2 different amounts of daily exercise (≈1.9 MJ/d and ≈3.4 MJ/d). These authors reported that EI did not increase in response to increased TEE in men, but there was ≈33% compensation in EI by women. The compensation in EI by the women was due to an increased consumption of foods that contained carbohydrate and fat, but not protein. The results of these experiments support the concept that active women compensate for their higher TEE by increasing EI more than do active men. However, the significance of the sex differences observed in these studies is debatable, because the authors reported that there were no treatment × sex effects for EI when the data were pooled (28).

The results of the dietary recalls should be interpreted with caution, because of potential limitations of the 24-h recall technique. These and other techniques are susceptible to problems such as underreporting (generally about 20%) and reactivity (unintentional or intentional decrease in food intake during the recording period), which may result in a misreporting of the absolute intake of nutrients (29). According to the technique proposed by Black (30), the recalls from 21% of the women and 14% of the men were likely misreported. The differences between EI and TEE in the women and men were −1.8 MJ/d and −0.6 MJ/d, respectively, which indicates an improbable negative energy balance in both sexes. It is worth noting that when the data were reanalyzed with these subjects removed, the results were not significantly altered. Despite these limitations, the relations between EE and food intake may not be altered by poor reporting, and thus the conclusions of the study would not be changed (29).

Finally, it is possible that sex-specific differences in metabolism may explain the lack of a significant relation between PAEE and %BF and the role that food intake plays in that relation. There are known sex differences in basal and exercise substrate oxidation (31), postabsorption lipolysis (32), storage of dietary fatty acids (33), and postmeal glucose flux and whole-body insulin sensitivity (34). Perhaps the combination of these factors and differences in carbohydrate and fat intake could result in greater fat deposition, sparing of endogenous body fat stores, or both. Unfortunately, none of these variables were measured in this study.

In conclusion, the relation between PAEE and %BF is negative and statistically significant only in men. A possible explanation for the lack of a relation in women may be the carbohydrate and fat intakes in their diet. Future research must focus on more accurate methods of tracking food intake and must investigate means to reduce the potential for body fat accumulation in women.

DRP was responsible for statistical analysis and manuscript preparation. JAN and WVR were responsible for all phases of the experiment. No author had any financial interest in the organization that sponsored the research (USDA).

REFERENCES

1. Kromhout D, Saris WHM, Horst CH. Energy intake, energy expenditure and smoking in relation to body fatness: the Zutphen Study. Am J Clin Nutr 1988;47:668–74.
2. Westerterp KR, Goran MI. Relationship between physical activity related energy expenditure and body composition: a gender difference. Int J Obes Relat Metab Disord 1997;21:184–8.
3. Bouchard C, Deprés JP, Tremblay A. Exercise and obesity. Obes Res 1993;1:133–47.
4. Westerterp KR. Obesity and physical activity. Int J Obes Relat Metab Disord 1999;23(suppl 1):59–64.
5. Roberts SB, Heyman MB, Evans WJ, Fuss P, Tsay R, Young VR. Dietary energy requirements of young adult men, determined by using the doubly labeled water method. Am J Clin Nutr 1991;54:499–505.
6. Rising R, Harper IT, Fontvielle AM, Ferraro RT, Spraul M, Ravussin E. Determinants of total daily energy expenditure: variability in physical activity. Am J Clin Nutr 1994;59:800–4.
7. Westerterp KR, Meijer GAL, Kester ADM, Wouters L, ten Hoor F. Fat-free mass as a function of fat mass and habitual activity level. Int J Sports Med 1992;13:163–6.
8. Westerterp KR, Meijer GAL, Janssen EME, Saris WHM, ten Hoor F. Long-term effect of physical activity on energy balance and body composition. Br J Nutr 1992;68:21–30.
9. Donnelly JE, Hill JO, Jacobsen DJ, et al. Effects of a 16-month randomized controlled exercise trial on body weight and composition in young, overweight men and women. Arch Intern Med 2003;163:1343–50.
10. National Center for Health Statistics. Plan and operation of the third National Health and Nutrition Examination Survey, 1988–94. Series 1: Programs and collection procedures. Vital Health Stat 1 1994:1–407.
11. Howe JC, Rumpler WV, Seale JL. Energy expenditure by indirect calorimetry in premenopausal women: variation within one menstrual cycle. J Nutr Biochem 1993;4:268–73.
12. de Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 1949;109:1–9.
13. Seale JL, Rumpler WV. Comparison of energy expenditure measurements by diet records, energy intake balance, doubly labeled water and room calorimetry. Eur J Clin Nutr 1997;51:856–63.
14. Schoeller DA. Measurement of energy expenditure in free-living humans by using doubly labeled water. J Nutr 1988;118:1278–89.
15. Black AE, Coward WA, Cole TJ, Prentice AM. Human energy expen-

diture in affluent societies: an analysis of 574 doubly-labelled water measurements. Eur J Clin Nutr 1996;50:72–92.
16. McDowell MA, Briefel RR, Warren RA, Buzzard IM, Feskanich D, Gardner SN. The Dietary Data C system. An automated interview and coding system for NHANES III. Proceedings of the 14th National Nutrient Databank Conference. Ithaca, NY: CBORD Group, Inc, 1990.
17. Nutrient Database Versions 15-25. Minneapolis: University of Minnesota, Nutrition Coordinating Center, 1996.
18. Carpenter WH, Poehlman ET, O'Connell M, Goran MI. Influence of body composition and resting metabolic rate on variation in total energy expenditure: a meta-analysis. Am J Clin Nutr 1995;61:4–10.
19. Schulz LO, Schoeller DA. A compilation of total daily energy expenditures and body weights in healthy adults. Am J Clin Nutr 1994;60:676–81.
20. Kuczmarski RJ. Prevalence of overweight and weight gain in the United States. Am J Clin Nutr 1992;55(suppl):495S–502S.
21. Schoeller DA, Jefford G. Determinants of the energy costs of light activities: inferences for interpreting doubly labeled water data. Int J Obes Relat Metab Disord 2002;26:97–101.
22. Prentice AM, Goldberg GR, Murgatroyd PR, Cole TJ. Physical activity and obesity: problems in correcting expenditure for body size. Int J Obes Relat Metab Disord 1996;20:688–91.
23. Allison DB, Paultre F, Goran MI, Poehlman ET, Heymsfield SB. Statistical considerations regarding the use of ratios to adjust data. Int J Obes Relat Metab Disord 1995;19:644–52.
24. Blundell JE, Stubbs RJ. High and low carbohydrate and fat intakes: limits imposed by appetite and palatability and their implications for energy balance. Eur J Clin Nutr 1999;53(suppl 1):S148–65.
25. Stubbs J, Ferres S, Horgan G. Energy density of foods: effects on energy intake. Crit Rev Food Sci Nutr 2000;40:481–515.
26. Jéquier E. Pathways to obesity. Int J Obes Relat Metab Disord 2002; 26(suppl 2):S12–7.
27. Stubbs RJ, Sepp A, Hughes DA, et al. The effect of graded levels of exercise on energy intake and balance in free-living women. Int J Obes Relat Metab Disord 2002;26:866–9.
28. Stubbs RJ, Sepp A, Hughes DA, et al. The effect of graded levels of exercise on energy intake and balance in free-living men, consuming their normal diet. Eur J Clin Nutr 2002;56:129–40.
29. de Castro JM. Eating behavior: lessons from the real world of humans. Nutrition 2000;16:800–13.
30. Black AE. The sensitivity and specificity of the Goldberg cut-off for EI:BMR for identifying diet reports of poor validity. Eur J Clin Nutr 2000;54:395–404.
31. Blaak E. Gender differences in fat metabolism. Curr Opin Clin Nutr Metab Care 2001;4:499–502.
32. Jensen MD. Gender differences in regional fatty acid metabolism before and after meal ingestion. J Clin Invest 1995;96:2297–303.
33. Romanski SA, Nelson RM, Jensen MD. Meal fatty acid uptake in adipose tissue: gender effects in nonobese humans. Am J Physiol Endocrinol Metab 2000;279:E455–62.
34. Robertson MD, Livesey G, Mathers JC. Quantitative kinetics of glucose appearance and disposal following a ^{13}C-labelled starch-rich meal: comparison of male and female subjects. Br J Nutr 2002;87:569–77.